GENERAL ELECTRIC
COMPANY

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COMPUTER DEPARTMENT
6757
DEER VALLEY PARK PLANT

Date June 20, 1962
Enclosure CPB 184, 185, 195
cc: R 1

T. Nelson, Ed. of Lab. Bul.
Dept of Social Relations
Harvard University
Cambridge 38, Massachussets

Dear Sir:

Thank you for your recent interest in the products of General Electric Computer Department. The material you requested is enclosed.

In addition, we are attaching a prepaid return card which we trust you will complete and return to us if you wish additional information on our products and services, or if you would like assistance with your computing requirements.

Very truly yours,

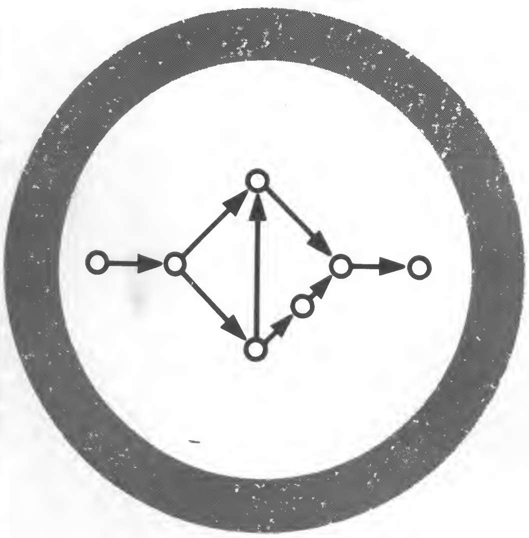
F. S. Stearns

F. S. Stearns, Mgr.
Marketing Section Services

CPB-195

TAKING THE GUESSWORK OUT OF DECISION MAKING

COMPUTER-BASED GUIDANCE FOR NEW PRODUCT VENTURES



for project planning, scheduling and control with the GE 225

COMPUTER DEPARTMENT

GENERAL ELECTRIC

by Børge M. Christensen and Jay R. Greene General Electric Computer Department, Phoenix, Arizona

PLANNING, SCHEDULING, AND CONTROLLING THE LAUNCHING OF A NEW PRODUCT VIA CPM.

by

Børge M. Christensen

J. R. Greene

October 1961

Continued survival of a firm in an increasingly competitive market environment requires a sound program of new product offerings. Those companies which have been able to maintain a steady stream of improved products, in timely anticipation of customer needs, not only have survived but also normally have prospered.

Recognizing this fact, during recent times more and more dollars have been invested in research and development efforts in the laboratories to insure that business enterprises will be well stocked with promising new ideas. However, hard experience has shown that the mere generation of product ideas is not sufficient to guarantee commercial success. There also must be a well integrated approach to the planning, scheduling, and controlling of new product programs.

Although the elements which are part of any new product program are discussed extensively in the literature[1], little has been provided in the way of a systematic methodology which will assist marketing managers in answering such questions as:

- What is the detailed schedule of activities to complete the launching from beginning to end at minimum cost and time? If a delay occurs at a specific point, how much additional effort, time, or cost must be expended to counteract the delay, and where?
- What and how much labor in various skills is required at a particular time?
- What is the status of the project in relation to the scheduled completion date?

Conceptually, the problems and questions associated with the launching of a new product are analogous to those encountered in a variety of other programs. For example, the construction of an office building requires integration among, and the successful completion of, a great number of interrelated activities within time and cost restraints. Similar situations are found in the development of large-scale military weapon systems or the maintenance shut-down of a refinery.

In recent years competition on one front or another has led to the development of several mathematically oriented techniques which, in conjunction with computers, provide factual project management data.[2] The result has been faster and more accurate answers to questions related to the planning and scheduling of projects, and tighter and more effective control during their implementation.

In the following sections of this article, we shall show how the first of these techniques to incorporate both time and cost information, namely the Critical Path Method, developed by Mauchly Associates Inc., can be applied to the important marketing problem of launching a new product.

[1] See, for example: American Management Association, Developing A Product Strategy, Management Report Series Number 39, New York, 1959.

Conrad Jones and Samuel C. Johnson, "How to Organize for New Products", Harvard Business Review, Vol. 35, No. 3, May - June 1957, pp. 49-62.

Philip Marvin, Planning New Products, (Cleveland: Penton Publishing Company, 1958).

C. Wilson Randle, "Weighing the Success of New Product Ideas", Industrial Marketing, July 1957, pp. 37-40.

[2] A. Astrachan, "Better Plans Come From Study of Anatomy of an Engineering Job". Business Week, March 21, 1959, pp. 60-66.

Børge M. Christensen, "How to Take the Guesswork Out of Project Planning", The Iron Age, August 3, 1961, pp. 67-69.

Børge M. Christensen, "The Critical Path Method, an Optimizing Time-Cost Planning and Scheduling Method", General Electric Company Publication CPB 184, July 1961.

D. G. Malcolm, J. H. Roseboom, G. E. Clark and W. Fazar, "Application of a Technique for Research and Development Program Evaluation", Operations Research, Vol. 7, 1959, pp. 646-669.

Fundamentals of the Critical Path Method

The initial step in applying the Critical Path Method (CPM) involves definition of each activity which must be performed in a project and its relationship to all other activities. This is facilitated by the use of a graphic technique--the arrow diagram. In the diagram, arrows indicate each activity in the project. The presence of an arrow depicts the existence of an activity. Time flows from the arrow's tail to its head. The length of an arrow carries no significance; only relative position of arrows is of interest.

An example of a very simple arrow diagram is shown in Figure 1. A few of the precedence relationships among the activities in this hypothetical project are as follows:

1. "Preliminary Market Investigations and Specifications" can be started following any lead time between the time of planning and the time the project is to be started.

2. "Engineering Design" must be fully completed before "Trial Manufacture" can be started.

3. A "Management Go-Ahead Decision" cannot be made until the financial analysis, the final design, and the layout of the advertising campaign are all fully completed and their results available.

With respect to the number of arrows in the network, it is often found that considerable detail is beneficial and that a gross treatment tends to obscure significant relationships and lessens the advantages of the technique. In practice, therefore, one would expect that each of the arrows in Figure 1 would be replaced by several arrows in series or parallel and with additional head-tail connections. The comprehensiveness of the diagram will depend in large measure on the purposes for which it is drawn.

Construction of the network is facilitated by determining three precedence relationships for each arrow: (1) activities that must immediately precede, (2) activities that immediately follow, and (3) activities that can be performed concurrent with the one under consideration. Proceeding in this manner, one builds the diagram arrow-by-arrow.

Considerable benefit can be derived from the arrow diagramming phase of project planning alone. The concept of the arrow diagram provides an orderly procedure for planning and results in an easily interpreted visual representation of the project scope. Consequently, it is an excellent vehicle for communicating both the macroscopic and microscopic aspects of the program to all project personnel.

Although the logic of the plan as established in the diagram may be agreeable to all concerned, it does not necessarily represent a feasible or desirable way of implementing the project. Only when time and costs are associated with each of the planned activities will it be possible to evaluate the over-all plan.

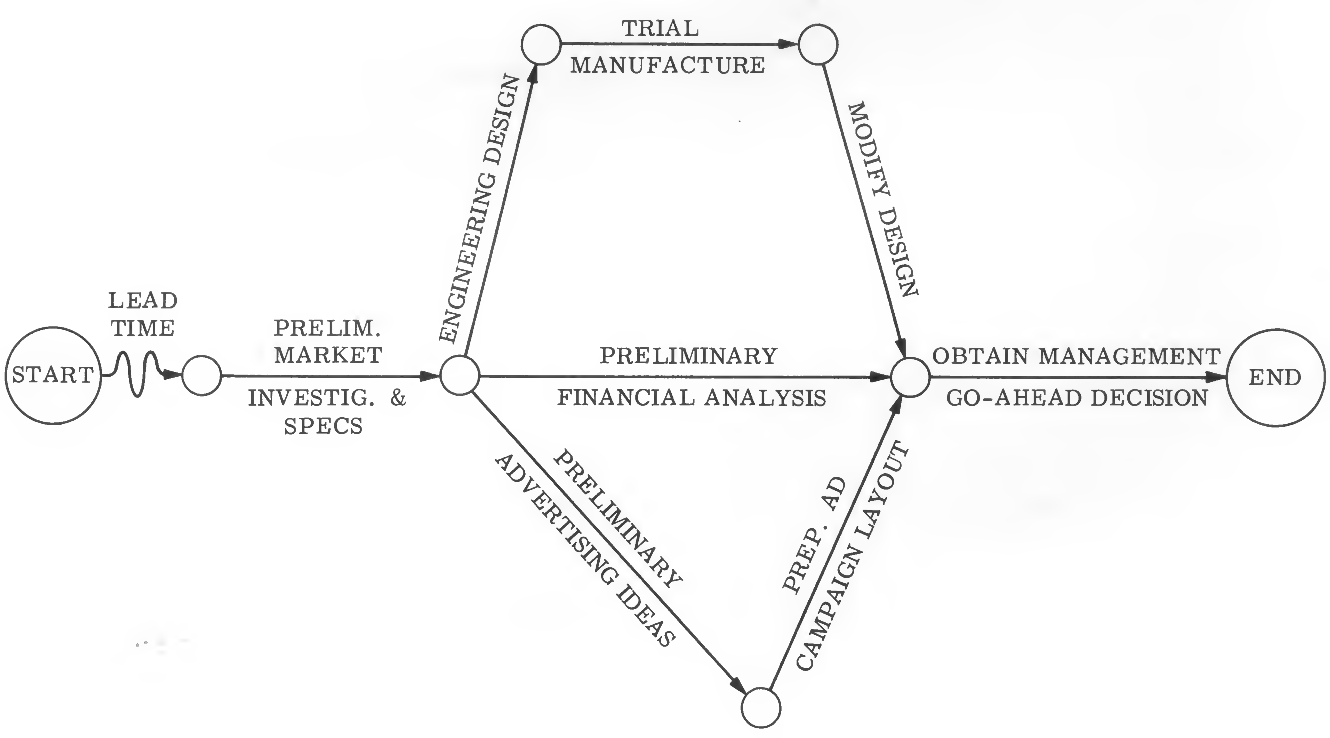


Figure 1: Arrow diagram of simplified project.

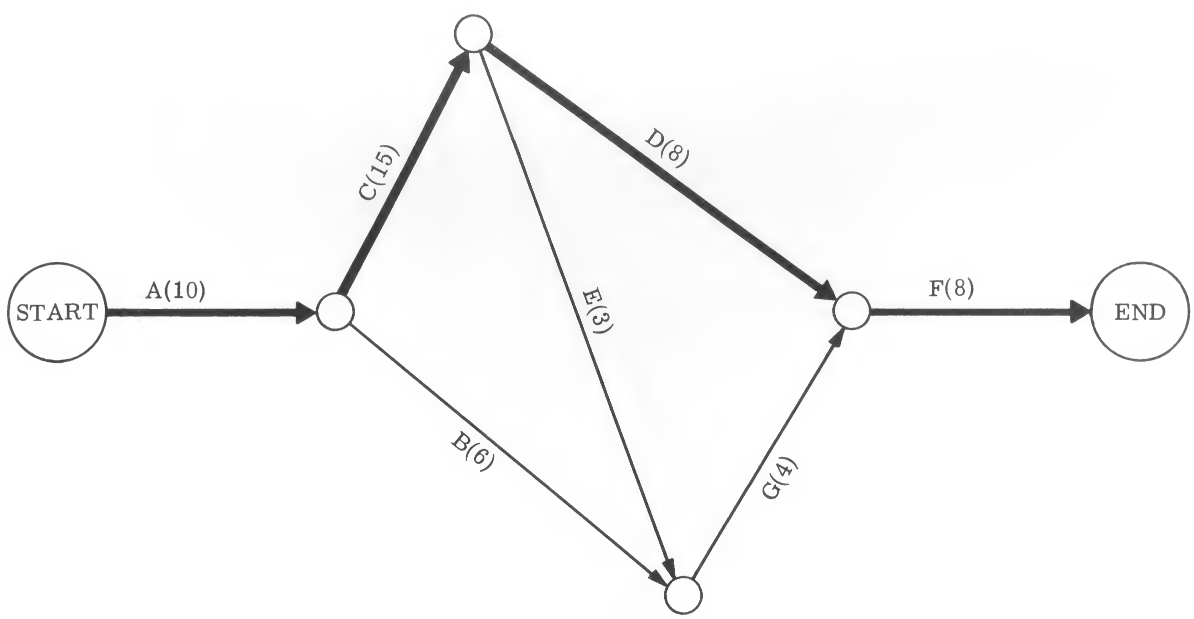
For each activity there exists a range of possible completion times. In general, as time is compressed direct costs increase. The shortest time in which an activity can be completed is termed the crash time; the minimum direct investment required to complete the activity in the crash time is defined as the crash cost. The lowest direct cost to complete the activity is known as the normal cost; the corresponding minimum duration constitutes normal time. Investments in excess of the crash cost do not contribute to expediting the activity; extensions beyond the normal time only result in additional costs.

The over-all project investment and completion time will vary with the combination of duration times selected for the individual activities. The sum of selected durations along one or more directed sequences of arrows--or paths--will be higher than the sum along all remaining paths. The largest sum indicates the required duration for the entire project, and the activities represented by the arrows along the corresponding path are critical activities. This is the critical path. Thus, in Figure 2 the critical path is comprised of activities A, C, D, and F, since the numerical values associated with these letters represent the longest path through the network.

Since the activity durations along a critical path always add up to the project duration, the non-critical activities will have some leeway for their performance, i.e., the available time is longer than the required time. As critical activities are compressed in order to obtain alternative project durations, the leeway may be absorbed and new critical paths may develop. Conversely, if any critical activity is delayed during implementation of the project, the over-all project duration will be extended by an equal time.

As an illustration, a simple arrow diagram is shown in Figure 3. The activities are identified by letters, and normal and crash cost and duration information is given directly on each arrow. Considering only normal times and normal cost, the activities shown with heavy arrows form a critical path with an over-all project duration of 38 days and result in a minimum planned project cost of $595.

If it were desired to complete this project in less time, say 37 days, it could be accomplished only by planning to expedite one of the critical activities E, D, G, H, or I. Expediting non-critical activities (A, B, C, or F) would not affect the project duration but would only serve to increase project costs.



	A = 10	A = 10	A = 10
	C = 15	C = 15	B = 6
	D = 8	E = 3	G = 4
	F = 8	G = 4	F = 8
		F = 8	
TOTAL TIMES:	41	40	28

Figure 2: Simple arrow diagram. Normal activity durations are shown on the arrows. The critical path is shown with heavy line arrows.

The least expensive way of expediting this project is accomplished by planning completion of activity D in one day less than the normal time. This is true because the cost to expedite D by one day is $15, which is less than that for any other activity on the critical path.

To obtain the shortest possible time for the project, it is necessary to compress all of the critical activities to their crash points. Doing this, the project duration becomes 26 days and the corresponding cost $920.

Successive compression of project duration and the associated minimum project costs can be shown graphically as a curve with the general shape indicated in Figure 4. The points above the curve indicate alternative, but more expensive, combinations of activity durations to obtain similar over-all project lengths. In most practical projects there will be an astronomical number of project-duration, project-cost combinations.

The least cost curve in Figure 4 is called the Direct Project Cost Curve because only direct costs were considered when the activity time-cost relationships were established.

Computational procedures have been established not only for development of the Direct Project Cost Curve but also for simultaneous calculation of activity characteristics corresponding to each project duration, such as earliest possible start time for an activity, latest allowable finish time, criticality status and amount of leeway, and scheduled cost. Using electronic computers programmed for CPM, one can in a matter of minutes obtain all of this information in a clearly tabulated form. (See Figure 8.)

There are great advantages in selecting from all existing project-duration, project-cost combinations those schedules for which direct cost is the lowest possible amount. In addition, the Direct Project Cost Curve shows the range of possible project durations and, therefore, immediately informs the planner of the possibility of meeting a pre-set project deadline.

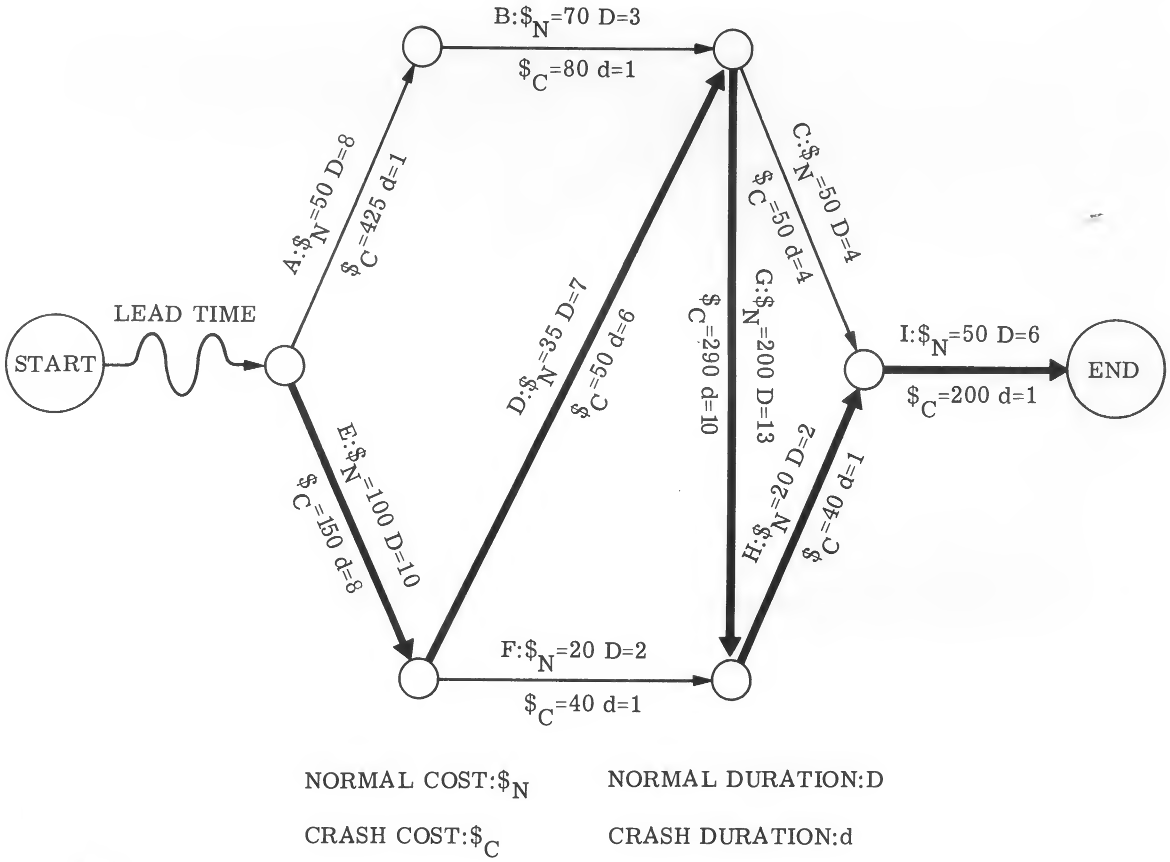


Figure 3: Simple arrow diagram. Normal and crash time and cost information is given along each arrow. Normal project duration is 38 days at a cost of $595. Fully crashed, the project can be done in 26 days at a minimum direct cost of $920.

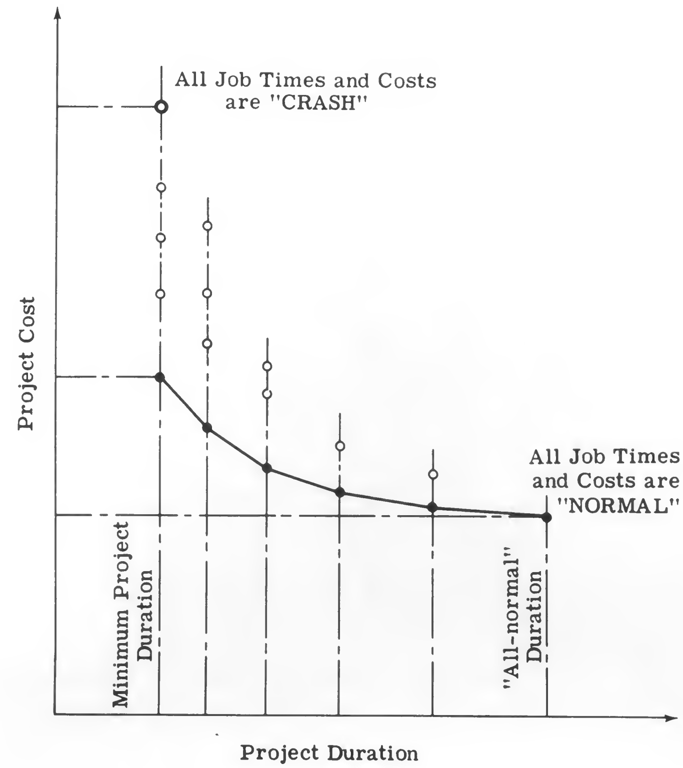


Figure 4: Typical Direct Project Cost Curve. Between the "all-normal" and minimum project durations exist (in this case) four partly expedited possible project durations. In any real project hundreds of possibilities exist for project duration and cost combinations. The mathematical procedure of CPM determines the lowest direct cost and the associated activity characteristics for each possible project duration. In the figure, the lowest direct costs are connected to form a piecewise linear curve.

Although the analyses based on the direct project cost data are useful in themselves, additional benefits can be derived by considering the indirect project costs so that the total anticipated cost of implementing the project under alternative schedules can be determined. The sum of direct and indirect costs result in a "U" shaped Total Project Cost Curve. An idealized case is shown in Figure 5.

The Total Project Cost Curve finds many uses. Its primary function is in the selection of that schedule which will require a minimum total investment for its implementation. The project duration corresponding to this minimum is indicated at the bottom point of the "U" shaped curve.

With this brief introduction to the Critical Path Method in terms of its fundamental building blocks, let us consider a hypothetical but realistic application of the method.

Implementing The Critical Path Method: A Case Study

The Victoria Company's Appliance Division has been charged with the responsibility of expanding the company's consumer product line by placing a small appliance on the market. A decision has been made to take advantage of the seasonal demand which occurs for this kind of appliance prior to each Christmas period. It is known that many small appliances are purchased as gift items and that most gift sales occur between the middle of November and the 24th of December. After Christmas day, gift sales fall off sharply. Consequently, it has been decided that sales should start on or about November 15. A project manager has been named and has decided to use the Critical Path Method. A properly programmed computer is available. Five steps are involved.

Step 1: Preparing the arrow diagram. The project manager's first job is to arrange for the construction of an arrow diagram. While consulting with the many functional groups that will be involved in the project, a diagram is prepared which depicts the logical precedence between each major activity in the contemplated project. The resulting diagram is shown in Figure 6.

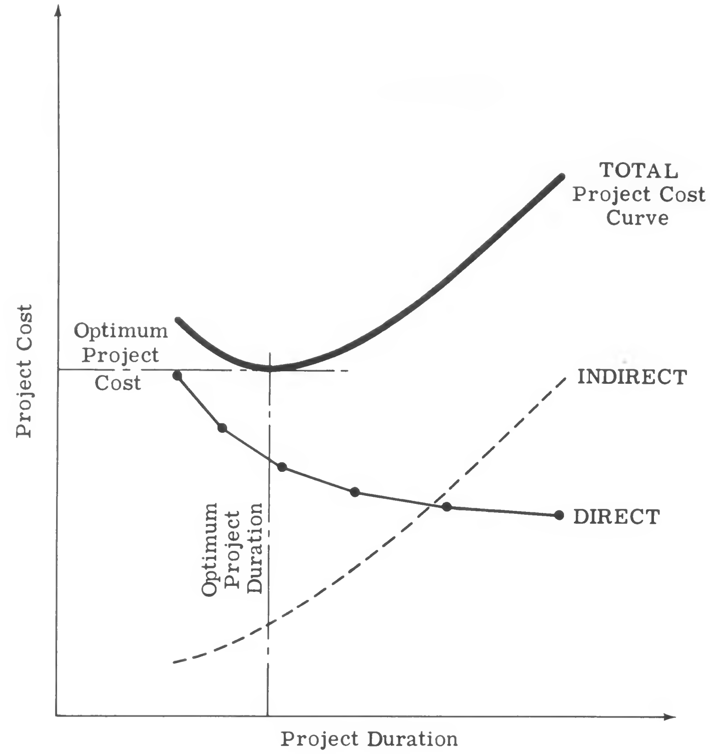


Figure 5: Typical Total Project Cost Curve. The Total Project Cost Curve is the sum of the Direct Project Cost Curve determined by CPM and the Indirect Project Cost Curve decided upon by the user. The optimum schedule is indicated by the minimum on the Total Project Cost Curve. The associated activity characteristics are found directly from the information produced by the GE 225 CPM program.

The level of detail in Figure 6 is sufficient for over-all project management. At a later time, functional managers may draw additional arrow diagrams which will assist them in planning, scheduling, and controlling the identified project tasks that are under their individual jurisdictions.

In Figure 6 some of the work elements are subdivided into several phases. This indicates that the start of some activity is dependent upon the partial, but not final, completion of the subdivided activity. For example, the engineering work must be brought to some state of completion before patent search can be started.

Four additional comments should be made about the diagram. First, it will be noted that the junctions where arrow heads and arrow tails meet have been numbered. This is done to provide a unique reference for each activity which can in turn be communicated readily to the computer. For example, the activity "Motivation Research" from Junction 1 to Junction 3 is identified as (1, 3). The junctions are called events since they signify the event of starting or completing one or more activities.

Second, several activity arrows are shown as broken lines and are known as dummies. These arrows do not indicate actual work elements, but rather are restraints used to maintain a proper precedence relationship in the diagram. They are treated by the computer as ordinary activities but do not require the expenditure of resources--either time or money. For instance, the restraint (27, 29) indicates that "Review and Revise Design" together with "Refining Advertising Campaign Ideas" must both precede the "Preliminary Media Selection". However, only "Review and Revise Design" must precede "Consolidate Trial Manufacturing Specifications".

Third, the wavy line (0, 1) is known as Lead Time. Event 0 is the current instant of time and Event 1 is when the project is scheduled to start. These two events, of course, could be concurrent. Arrows have been drawn from Event 0 to Events 17 and 36 to show that top management must be available at the latter two points if the project is to proceed. If management can only be available at earlier times, it may be possible to shorten the lead time to conform to their schedule restraint. If in this situation the amount of lead time is less than the required compression, some activities may be forced into

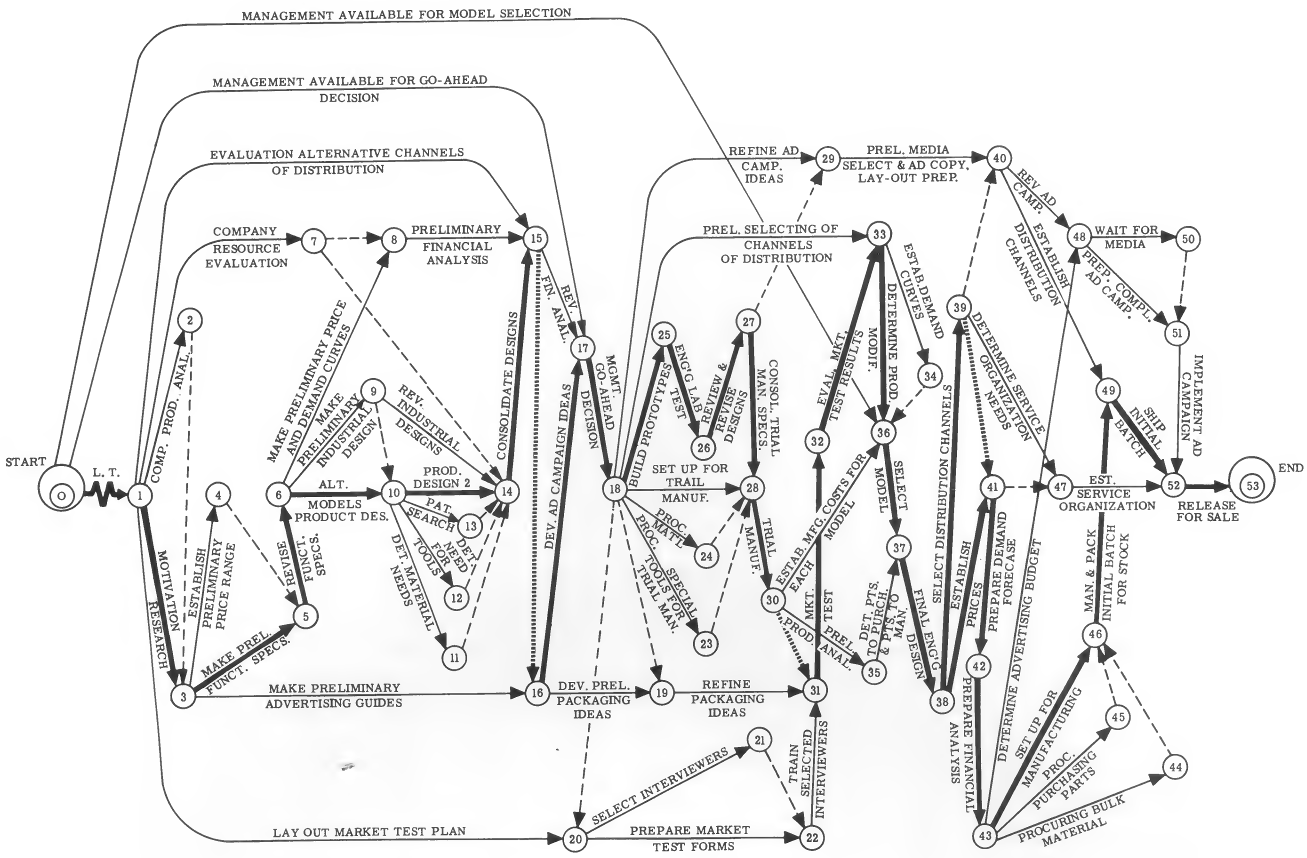


Figure 6: Arrow diagram for launching product XYZ. Time-cost information is not shown, but the critical path for the all-normal case is indicated with heavy lines.

otherwise unnecessary crashing. The resulting increased costs can be related directly to management's unavailability. At times, the elimination of all lead time and a complete crashing of the project will not provide sufficient time compression and project completion will be unavoidably delayed. Again, responsibility can be placed where it belongs. In case management can only be available after Events 17 and 36 should start, lead time may be extended with a possible corresponding delay in project duration.

The fourth and final comment is that the diagram has been drawn so that both project START and project END are identified by single events, Events 0 and 53, respectively.

Step 2: Completing the input data for computer calculations. In addition to the numbered diagram the project manager must arrange to provide time-cost information about each activity. In the great majority of cases it can with sufficient accuracy be assumed that cost rises linearly as attempts are made to expedite an activity. It is therefore only necessary to establish normal costs, normal durations, and crash costs and crash durations. In cases where the linearity assumption does not hold, a piecewise linear approximation can be made. The linearity assumption eases the burden of data collection considerably. There also exists the possibility that only normal or crash duration can be implemented. Such discontinuity must be specified.

The successive expediting of the project duration is based on the relative slopes of the activity time-cost relationships. By specifying artifically large time-cost slopes for selected activities, the project manager can exert his influence on the sequence in which these activities are considered for expediting.

The computer program used for the processing of this example--the GE 225/CPM program--offers the user an opportunity to bias the allocation of leeway or float time. To this end, a priority weight--a number from one through nine--is given to each activity. The priority weighting scheme allocates any available float to activities in proportion to the established weights. In cases where uncertainty on duration estimates is abnormally high, one would use a high priority weight and consequently would expect a proportionally high amount of float to be scheduled for that activity. For practical reasons, the float allocation by priority weights is augmented in the GE 225 program by a built-in bias which conserves float for activities located late in a project.

GENERAL ELECTRIC GE 225 Critical Path Method Input Code Sheet

PAGE 3 OF 10

LEGEND

I — THE EVENT NUMBER AT THE TAIL OF THE ACTIVITY ARROW.
J — THE EVENT NUMBER AT THE HEAD OF THE ACTIVITY ARROW.
D — THE NORMAL DURATION FOR THIS ACTIVITY.
d — THE CRASH DURATION FOR THIS ACTIVITY
W — A DIGIT FROM 1 TO 9 - THE WEIGHT OF THIS ACTIVITY IN RELATION TO OTHER ACTIVITIES (FOR PURPOSES OF FLOAT ASSIGNMENT).
C/N — A CONTINUOUS OR NON-CONTINUOUS COST CURVE (SPECIFY).

I	J	D	d	NORMAL COST	CRASH COST	SLOPE (Optional)	W	C/N	ACTIVITY DESCRIPTION
6	9	4	2	400	700		4	N	302 MAKE PRELIMINARY INDUSTRIAL DESIGNS PHASE 1
6	10	20	18	4000	4200		9	C	301 ALTERNATIVE MØDELS PRØDUCT DESIGN PHASE 1
7	8	0	0	0	0		1	C	000 DUMMY
7	14	0	0	0	0		1	C	000 DUMMY
8	15	2	2	300	300		5	C	402 PRELIMINARY FINANCIAL ANALYSIS
9	10	0	0	0	0		1	C	000 DUMMY
9	14	8	5	800	1500		4	N	302 REVISED INDUSTRIAL DESIGNS PHASE 2
10	11	3	3	120	120		6	C	303 DETERMINE MATERIAL NEEDS
10	12	3	3	120	120		6	C	303 DETERMINE NEED FØR SPECIAL TØØLS
10	13	40	20	1000	1500		8	C	401 PATENT SEARCH

PREPARED BY JRG - BMC DATE 10/1/61

Figure 7: Page 3 of the GE 225 CPM input code sheet for the new product launching project shown in Figure 6.

Step 2 is completed when all of the required information is collected and listed on input code sheets. Figure 7 shows page 3 of the code sheets prepared for this example. Each line on the page corresponds to one activity and can contain up to 80 columns of information. Columns 1 through 28 contain precedence, time, cost, slope, weight, and continuity information. The dummies are entered with zero time, zero cost requirements, and minimum weights. Activities that cannot be expedited, such as "Determine Material Needs" (10, 11) have normal time equal to crash time and normal cost equal to crash cost.

The remaining columns, 29 through 80, are reserved for an alpha-numeric activity description. A code can be included in this description to facilitate identification of, for instance, areas of responsibility. Similarly, job account numbers or any other desired code may be included.

Activity responsibility resting with Executive Management has been coded in this example in the 500-series, Finance and Legal responsibility is coded in the 400-series, Engineering in the 300, Manufacturing in the 200, and Marketing responsibility in the 100-series.

<u>Step 3: Computing schedules</u>. A deck of input cards is next keypunched on the basis of the input code sheet, one card for each activity. The cards will contain all the project information necessary to communicate with the computer. If processed with a CPM program package which contains the proper step-by-step interpretation of the mathematical CPM formulation, the result will be a computer output consisting of a series of tabulated, alternative schedules. Each schedule will constitute a complete, detailed timetable for a given project duration. Besides repeating the pertinent portion of the input information, the output table will list:

- Criticality status of each activity.
- Time and cost required for each activity in order to implement the particular schedule.
- Change in activity times and costs as compared to the preceding schedule.
- Scheduled finish of each activity in view of specified priority weights.
- Scheduled float for each activity as determined by priority weights and the activity's proximity to the last event in the project.
- Earliest possible and latest allowable start and finish of each activity.
- Total and free float for each activity.

<u>Total float</u> and <u>free float</u> have different significance. If total float is zero, the corresponding activity is critical. Free float is the amount of leeway available after implementation of an activity if all other activities in the project were started as early as possible. Should an activity last longer than planned but not long enough to absorb more than its free float, the delay will not interfere with the timely completion of any other portion of the project.

Figure 8 shows one of the expedited schedules, taken from the computer print-out. It includes all of the detailed activity characteristics for that schedule.

The least direct project costs corresponding to various project durations as prepared by the computer are summarized in Figure 9.

The range of project durations span from an all-normal duration of 399 days to a minimum duration of 247 days beyond which the project cannot be expedited. Had <u>all</u> jobs been expedited, the project duration would still have been 247 days, however, the cost would have skyrocketed to $219,000. This represents an unnecessary outlay of approximately $30,000, or 16 percent of the necessary direct project cost for the minimum duration.

The computation time required for each alternative least cost schedule for this example averaged four seconds.[3] In general, required processing time depends on the size and complexity of the arrow diagram. In addition to computation time, read-in of the activity cards and print-out of the tabulated schedules each require approximately two-tenths of a second per activity.

The range of project durations and the associated costs in Figure 9 are shown graphically in Figure 10 as the Direct Project Cost Curve. To show the total project cost picture, indirect expenses must be estimated and added. In most cases, indirect cost is considered to be a fixed percentage of some base cost. In the Victoria Company, a constant indirect cost rate of 150 percent of total normal duration cost is used. Therefore, the indirect cost of implementing the all-normal schedule is 150 percent of $129,940, or $194,910, corresponding to an indirect cost rate of $488 per day. The indirect cost for the minimum duration schedule is a total of $488 times 247 days, or $120,536. The constant indirect rate is shown as the straight, broken line in Figure 10.

<u>Step 4: Establishing the plan of implementation</u>. The final step of the planning and scheduling procedure is to select a specific plan of implementation, then translate relative times to a calendar-based schedule and allocate resources in accordance with the selected schedule.

[3] Four seconds processing time on the General Electric GE 225 Information Processing System corresponds to a processing cost of approximately 17 cents.

Launching Product XYZ - The Victoria Company, New Product Division
Example of CPM prepared on the GE 225

Figure 8

Activity		Crit. Status	Time	Chng.	Cost	Scheduled		Earliest		Latest		Float		Pri.
i j	Description					Fnsh	Float	Start	Fnsh	Start	Fnsh	Total	Free	Wt.
000 001	000 Lead Time	Crit	0					0		0				1
000 017	500 Management Available for Go-Ahead Decision		0				102	0		102	102	102	102	2
000 036	500 Management Available for Model Selection		0				205	0		205	205	205	205	2
001 002	102 Competitive Product Analysis	Crit	20		675	20		0	20	0	20			5
001 003	102 Motivation Research	Crit	20		15000	20		0	20	0	20			5
001 007	402 Company Resource Evaluation		8		480	8	1	0	8	87	95	87		2
001 015	102 Evaluate Alternative Channels of Dist.		10		500	10	90	0	10	90	100	90	90	2
001 020	102 Lay Out Market Test Plan		5		300	5	99	0	5	131	136	131	99	2
002 003	000 Dummy	Crit	0			20		20	20	20	20			1
003 004	102 Estimate Preliminary Price Range		2		130	22		20	22	33	35	13		2
003 005	102 Make Preliminary Functional Specifs.	Crit	15		1200	35		20	35	20	35			4
003 016	101 Make Preliminary Advertising Guides		10		1500	30	70	20	30	90	100	70	70	2
004 005	000 Dummy		0			22	13	22	22	35	35	13	13	1
005 006	102 Revise Functional Specifications	Crit	2		250	37		35	37	35	37			2
006 008	102 Make Preliminary Price & Demand Curves		3		175	40		37	40	95	98	58		2
006 009	302 Preliminary Indust. Designs Phase 1		4		400	41		37	41	51	55	14		4
006 010	301 Alter. Models Product Design Phase 1	Crit	18		4200	55		37	55	37	55			9
007 008	000 Dummy		0			9	31	8	8	98	98	90	32	1
007 014	000 Dummy		0			9	86	8	8	95	95	87	87	1
008 015	402 Preliminary Financial Analysis		2		300	42	58	40	42	98	100	58	58	5
009 010	000 Dummy		0			41	14	41	41	55	55	14	14	1
009 014	302 Rev. Industrial Designs Phase 2		8		800	49	46	41	49	87	95	46	46	4
010 011	303 Determine Material Needs		3		120	58	1	55	58	92	95	37		6
010 012	303 Determine Need for Special Tools		3		120	58	1	55	58	92	95	37		6
010 013	401 Patent Search	Crit	40		1000	95		55	95	55	95			8
010 014	302 Alter. Models Product Design Phase 2	Crit	40		11000	95		55	95	55	95			9
011 014	000 Dummy		0			59	36	58	58	95	95	37	37	1
012 014	000 Dummy		0			59	36	58	58	95	95	37	37	1
013 014	000 Dummy	Crit	0			95		95	95	95	95			1
014 015	300 Consol. Designs & Select Three Models	Crit	5		1300	100		95	100	95	100			8
015 016	000 Dummy	Crit	0			100		100	100	100	100			1
015 017	402 Revise Financial Analysis		1		60	101	1	100	101	101	102	1	1	1
016 017	101 Develop Advtg. Campaign Ideas	Crit	2		1000	102		100	102	100	102			6

Figure 8

Activity			Crit. Status	Time	Chng.	Cost	Scheduled'		Earliest		Latest		Float		Pri. Wt.
i	j	Description					Fnsh	Float	Start	Fnsh	Start	Fnsh	Total	Free	
016	019	101 Develop Preliminary Packaging Ideas		2		300	102	5	100	102	143	145	43	2	6
017	018	500 Management Go-Ahead Decision	Crit	2		2500	104		102	104	102	104			9
018	019	000 Dummy		0			104	3	104	104	145	145	41		1
018	020	000 Dummy		0			104		104	104	136	136	32		1
018	023	202 Procure Special Tools for Trial Mfg.		10		500	114	1	104	114	118	128	14		8
018	024	202 Procure Materials for Trial Mfg.		20		20	124		104	124	108	128	4		7
018	025	302 Build Prototypes	Crit	10		1800	114		104	114	104	114			3
018	028	203 Set Up for Trial Manufacture	Crit	24	-	8400	128		104	128	104	128			4
018	029	101 Refine Advertising Campaign Ideas		1		200	105	27	104	105	200	201	96	20	2
018	033	100 Preliminary Selection of Dist. Channels		2		250	106	95	104	106	199	201	95	95	2
019	031	101 Refine Packaging Ideas		3		450	110	38	104	107	145	148	41	41	2
020	021	102 Select Interviewers		10		200	114		104	114	136	146	32		2
020	022	102 Prepare Market Test Forms		3		120	107	7	104	107	143	146	39	7	2
021	022	000 Dummy		0			114		114	114	146	146	32		1
022	031	102 Train Selected Interviewing Personnel		2		600	116	32	114	116	146	148	32	32	5
023	028	000 Dummy		0			115	13	114	114	128	128	14	14	1
024	028	000 Dummy		0			124	4	124	124	128	128	4	4	1
025	026	302 Engineering Lab Tests	Crit	8		1100	122		114	122	114	122			9
026	027	302 Review and Revise Product Design	Crit	3		650	125		122	125	122	125			9
027	028	203 Consolidate Trial Mfg. Specifications	Crit	3	-	650	128		125	128	125	128			7
027	029	000 Dummy		0			125	7	125	125	201	201	76		1
028	030	201 Trial Manufacture	Crit	20		9000	148		128	148	128	148			7
029	040	101 Prel. Media Select & Ad Cpy, Lay-Out Prep.		15		3000	147	69	125	140	201	216	76	76	2
030	031	000 Dummy	Crit	0			148		148	148	148	148			1
030	035	303 Preliminary Product Analysis		4		400	152	2	148	152	200	204	52		2
030	036	201 Establish Mfg. Costs for Each Model		3		400	151	54	148	151	202	205	54	54	3
031	032	102 Market Test	Crit	50		10000	198		148	198	148	198			8
032	033	102 Evaluate Market Test Results	Crit	3		1500	201		198	201	198	201			3
033	034	102 Establish Demand Curves		3		300	204		201	204	202	205	1		3
033	036	303 Determine Product Modifications	Crit	4		800	205		201	205	201	205			9
034	036	000 Dummy		0			204	1	204	204	205	205	1	1	1
035	037	203 Determine Parts to Purchase & to Mfg.		3		300	157	50	152	155	204	207	52	52	2
036	037	500 Select Model	Crit	2		1000	207		205	207	205	207			5
037	038	303 Make Final Engineering Design	Crit	8		1200	215		207	215	207	215			9
038	039	100 Select Distribution Channels	Crit	1		400	216		215	216	215	216			2
038	041	100 Establish Prices	Crit	2		200	217		215	217	215	217			2

Activity			Crit. Status	Time	Chng.	Cost	Scheduled		Earliest		Latest		Float		Pri.
i	j	Description					Fnsh	Float	Start	Fnsh	Start	Fnsh	Total	Free	Wt.
039	040	000 Dummy	Crit	0			216		216	216	216	216			1
039	041	000 Dummy		0			216	1	216	216	217	217	1	1	1
039	047	103 Determine Service Organization Needs		5		500	221	14	216	221	249	254	33		4
040	048	101 Revise Advertising Campaign	Crit	12		2500	228		216	228	216	228			8
040	049	104 Establish Distribution Channels		40		4000	256	21	216	256	237	277	21	21	2
041	042	102 Prepare Demand Forecast	Crit	2		200	219		217	219	217	219			2
041	047	000 Dummy		0			217	18	217	217	254	254	37	4	1
042	043	402 Prepare Financial Analysis	Crit	3		600	222		219	222	219	222			2
043	044	202 Procure Bulk Material		25		50	247	7	222	247	242	267	20		8
043	045	202 Procure Purchased Parts		30		200	252	5	222	252	237	267	15		9
043	046	201 Set Up For Manufacture	Crit	45		22500	267		222	267	222	267			2
043	048	100 Determine Advertising Budget		1		300	223	5	222	223	227	228	5	5	2
044	046	000 Dummy		0			254	13	247	247	267	267	20	20	1
045	046	000 Dummy		0			257	10	252	252	267	267	15	15	1
046	049	201 Manufacture & Pkg Initial Batch for Stock	Crit	10		20000	277		267	277	267	277			9
047	052	103 Establish Service Organization		37		3700	272	19	221	258	254	291	33	33	3
048	050	101 Media Availability Lead Time	Crit	60			288		228	288	228	288			2
048	051	101 Prepare Complete Advertising Campaign		22		5200	250	38	228	250	266	288	38	38	5
049	052	204 Ship Initial Product Batch to Distrib'rs.	Crit	14		1334	291		277	291	277	291			2
050	051	000 Dummy	Crit	0			288		288	288	288	288			1
051	052	101 Implement Advertising Campaign	Crit	3		350	291		288	291	288	291			2
052	053	100 Release Product for Sale	Crit	2			293		291	293	291	293			1

Project Duration in Days 293
Direct Project Cost 148,184

Figure 8: 19th expedited schedule for the new product launching project. The table includes information identical to that prepared by the computer for each schedule.

Schedule	Project Duration in Days	Least Direct Project Cost in Dollars
All-normal schedule	399	129,940
1st expedited schedule	395	130,080
2nd expedited schedule	390	130,280
3rd expedited schedule	389	130,330
4th expedited schedule	388	130,380
5th expedited schedule	383	130,680
6th expedited schedule	380	130,860
7th expedited schedule	378	131,060
8th expedited schedule	348	134,060
9th expedited schedule	346	134,260
10th expedited schedule	344	134,460
11th expedited schedule	343	134,560
12th expedited schedule	342	134,760
13th expedited schedule	302	143,760
14th expedited schedule	301	144,060
15th expedited schedule	300	144,460
16th expedited schedule	299	144,894
17th expedited schedule	297	146,284
18th expedited schedule	295	147,234
19th expedited schedule	293	148,184
20th expedited schedule	283	153,184
21st expedited schedule	278	157,350
22nd expedited schedule	272	162,350
23rd expedited schedule	267	167,350
24th expedited schedule	252	182,350
Minimum-duration schedule	247	188,850

Figure 9: Summary of Computed Alternative Schedules

The project manager can observe the variation of total project cost associated with alternative project schedules by adding the Direct and the Indirect Project Cost Curves in Figure 10. The resulting Total Project Cost Curve--the "U" shaped curve in the figure--clearly indicates that the least expensive project duration can be obtained if the implementation is executed in accordance with Schedule 19 wherein the project time is 293 working days.

It is known that a high percentage of the total year's volume will occur between the middle of November and the 24th of December. Therefore, to maximize seasonal sales and minimize implementation cost, the most desirable schedule would be the one for which the 293rd working day corresponds to the calendar day of November 15.

The selected schedule, Number 19, is converted into a calendar-based schedule by properly accounting for Saturdays and/or Sundays, holidays, vacation shutdowns, and other non-working days, and then setting an appropriate lead time. If the time period from the current date to November 15 is greater than the calendar time required by Schedule 19, then of course that schedule--with its minimum total project cost benefit--can be used. If, however, the actual calendar time available is less than that required by Schedule 19, then a further expedited--and therefore more costly--schedule must be used in order to achieve a November 15 completion date.

Total company profit can be maximized only if the total project cost (from Figure 10) and the cost of lost sales volume resulting from delays beyond November 15 are considered simultaneously. Summing these costs results in a Composite Cost Curve. The minimum point on the Composite Cost Curve determines the over-all optimum schedule.

The composite cost situation for the Victoria Company is portrayed in Figure 11. In this case it is found to be the schedule corresponding to a project duration of 270 working days (i.e., Schedule 23). Thus, even though Schedule 19 would result in the lowest project implementation cost, the Christmas trade would be missed if that schedule were used and the composite cost would be $30,000 higher than that resulting from Schedule 23.

Placing the selected schedule on a calendar is accomplished by the computer with a simple calendar dating routine. The established timetable is then communicated to the various organizational components under whose jurisdiction responsibility for completion of individual activities belongs. Once in the hands of functional management, duration and cost information as tabulated in the computer output (cf., Figure 8) is used for allocation of manpower, equipment, and other resources.

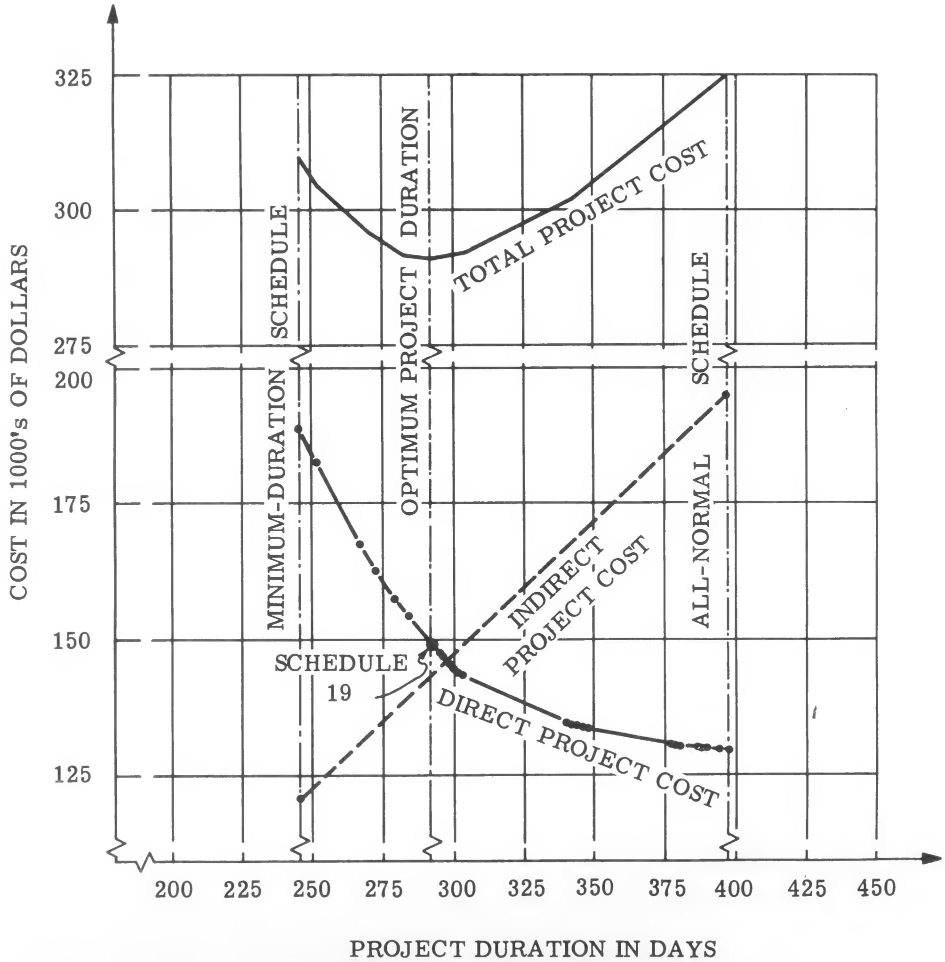


Figure 10: Direct, Indirect, and Total Project Cost Curves for new product launching example. Optimum project duration is 293 days.

Step 5: Controlling the project. Although originally developed as a project planning and scheduling tool, the Critical Path Method lends itself very well to the controlling of programs such as the one considered in this example. The project manager should receive periodic reports from functional managers, with frequency depending on project durations and personal preferences. Reports should include information regarding time and cost required for completion of activities under their respective jurisdictions. Based on these reports, new input cards are prepared for those activities for which time-cost requirements deviate from previous data. Using the computer the project plan can be rapidly updated. In addition to the regular reports, the project manager must be informed immediately when critical activities are delayed or non-critical activities extend beyond the available free float.

Analysis of the revised information may indicate that a new schedule is required for the remainder of the program if the original project duration is to be realized. If slippages have occurred, normally it is possible to eliminate their effect by developing a new schedule which specifies that subsequent critical activities be executed on a more expedited basis than was originally planned. When all remaining critical activities have already been scheduled to be fully crashed, management must resort to alternative approaches. Redefinition of critical activities yet to be implemented, and revisions in the arrow diagram, constitute two alternatives which can be taken.

Both of these possibilities usually require managerial risk decisions. CPM aids management by specifying the only activities for which such decisions will have the desired influence.

For example, redefinition of critical activities in the product launching project described above could occur if management decides that time does not permit the construction of more than two prototypes if the project completion date is to be met. The development of two prototypes, rather than many, increases the risk of not finding a suitable product. Management then must use its judgment as to whether it is willing to accept this risk.

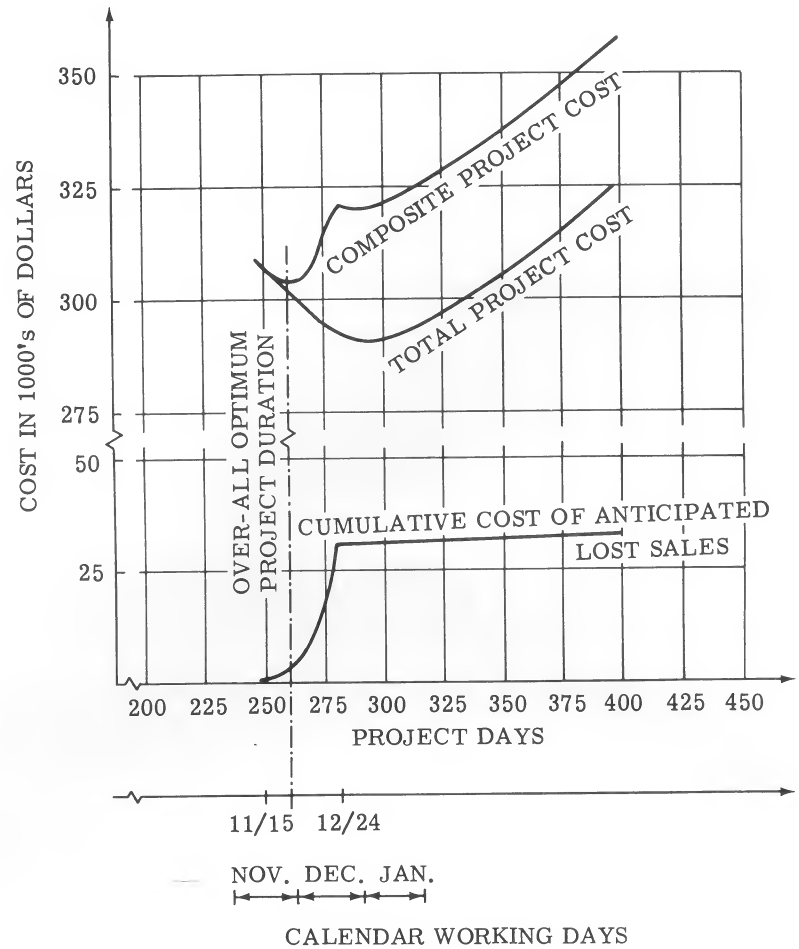


Figure 11: Composite cost variation with calendar time and project duration for product XYZ. The composite project cost is the sum of the total project cost and the cumulative cost of anticipated lost sales. "Project Day 0" must be specified before the calendar scale can be established.

Alternatively, the arrow diagram could be revised by a decision to eliminate all or portions of one or more activities. For example, in Figure 6 "Trial Manufacture"-- and consequently "Consolidate Trial Manufacturing Specifications"--may be eliminated, causing the junction points labeled 27, 28, and 30 to coincide in the revised diagram. Since both activities were on the critical path, additional time is made available for subsequent activities.

If all activities along the critical path have not been fully crashed, trade-offs can be considered between the cost of further crashing and the risk of changing the nature and quality of planned activities. By studying alternative computer runs before the actual method of expediting to be applied is decided upon, management decisions can be based on a wider range of factual data than is possible without CPM and the high-speed computer.

Concluding Remarks

In the foregoing portion of this article the Critical Path Method was discussed in some detail. Emphasis was placed on the application of the method to an important class of marketing management problems. It was demonstrated that CPM represents a basic tool available to all levels of management and that the technique included elements of timeliness, selection, and evaluation. CPM provides for true management by exception. The mathematical structure and the computational details of the method were omitted.

As presented here, the method considers only one project at a time, and allocation of total company resources is not necessarily optimum. Computer programs can, however, also be applied to inter-project scheduling and can be used to take into account the allocation of scarce resources among competing projects. In addition, methods exist which

will incorporate the uncertainty of time estimates more directly than does the priority weighting scheme. The result is a statistical evaluation of the probability of completing a project within established time and cost limits.

Discussion of these and other extensions of the fundamental principles of the method would lengthen this presentation unduly. Although the article has been limited to a consideration of the basic features of the Critical Path Method, the discussion has been sufficient to demonstrate that CPM is an extremely powerful tool which--in conjunction with the electronic computer--stands ready to help the business manager minimize the guesswork in decision-making.

The preceding article is to appear in Professor Wroe Alderson's book Marketing and the Computer, Prentice-Hall, 1962.

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